Tank Sloshing Validation

FLUENT has been used in this example to simulate the sloshing flow of liquid in a tank. The tank is subjected to a swaying motion, and the transient behavior observed in an experiment is well matched by the simulation. The results validate the volume of fluid, or VOF model that is popular for simulations involving immiscible fluids, such as the water and air used here. Deviations in the results are most likely due to approximations made in the simulation.

The experimental data provided by the National Maritime Research Institute of Japan is gratefully acknowledged.

The primary objective of this example is to validate the VOF model in FLUENT against existing experimental data from the National Maritime Research Institute (NMRI) of Japan. The VOF, or volume of fluid model, is suited to multiphase flows involving two or more immiscible fluids. The model has the ability to accurately capture the interface between the fluids for both steady-state or transient flows. The results of the present calculation are in very good agreement with data.

The apparatus used in the experimental studies of sloshing (Reference 1) allows many motions to be imposed on the tank: sway, pitch, heave, and roll, for example. Two of these motions are shown in Figure 1. The motions can be applied separately or in any combination. The three-dimensional tank is 1200 mm long, 600 mm high, and 200 mm deep. Since the front and back walls are smooth, frictional damping plays a small role on wave motion in the primary plane of the tank, so the flow can safely be approximated with a two-dimensional model.

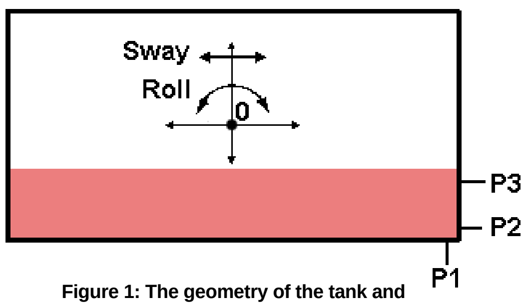

Figure 1: The geometry of the tank and positions of some of the pressure taps

Pressure taps for recording pressure variation with time are installed at 14 locations on the bottom, top, and right side walls. Three of these (P1, P2, and P3) are shown in Figure 1. In addition to pressure measurements, video recording was conducted over many periods of motion, allowing visual comparison of free-surface deformations in the experiment with those predicted by the simulation.

While several varieties of motion have been studied experimentally, only pure swaying motion with a single amplitude and period is considered here. (Experimental data are also available for several other sets of amplitude and period.) The motions are sinusoidal: $x = A \sin(\omega t)$, where A is the amplitude of motion (maximum displacement from the reference location) and ω is the frequency in radians/sec ($\omega = 2\pi/T$, where T is the period of oscillation). For the present case, the liquid was initially filled to 20% of the tank height, and an amplitude and period of A = 60 mm, and T=1.94 s, respectively, were considered. Video recordings of the flow visualization in MPEG format are available from NMRI on request.

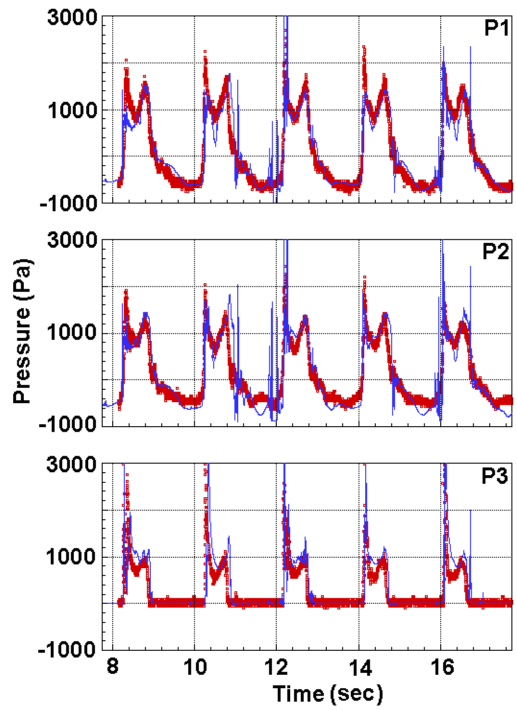

Figure 2: Pressure measured at three sites (red) is compared to simulation results (blue) at the same locations

Simulations were performed using FLUENT 5.6.2, using a 2D quadrilateral mesh consisting of 7200 cells. Simulations were started with the fluid initially at rest. Time steps of 2 ms were used in the solution of the conservation equations for mass, momentum, and volume fraction of the liquid.

The motion of the tank was incorporated by adding a time-varying body force, representative of the periodic tank acceleration, and computing the flow in a coordinate system attached to the tank. This simulated motion was implemented by a user-defined function (UDF). Since the inertial force due to the swaying motion is very large compared to the viscous forces in the fluids, a slip-wall boundary condition was imposed on the tank walls, and laminar flow was assumed.

The geometry of the tank and positions of three of the fourteen pressure taps are shown in Figure 1. The 2D tank lies in the x-y plane with its origin at the center. The tank motions studied in the experiment, including roll and sway, are centered about the origin, as shown.

Periodic pressure recorded at the three taps shown in Figure 1 is displayed in Figure 2 (red) along with FLUENT predictions at the same sites (blue). Despite the presence of some occasional spikes in the simulation reports, the overall agreement is very good at all three locations. These results suggest that the VOF model along with approximations described above is well suited for fluid motion of this type.

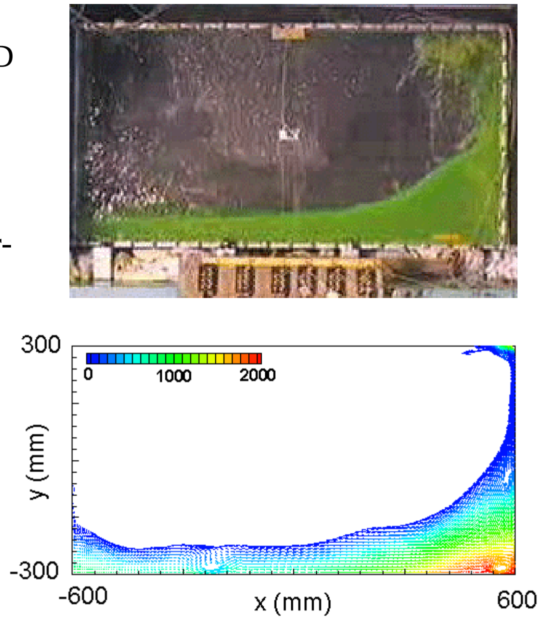

Figure 3: FLUENT results (bottom) are compared to a photograph at the same time in the oscillation cycle (top)

In Figure 3 (top), a photograph of the experiment is taken when the liquid has sloshed up the right hand wall, hit the ceiling, and is beginning to fall back to the bottom of the tank. An image from the transient FLUENT simulation at this same instant in time is also shown (bottom). Velocity vectors are shown in the liquid in the simulated image, colored by static pressure. FLUENT closely captures the motion of the liquid, and has the ability to provide more information about the fluid behavior (in the form of the instantaneous velocity and pressure fields) than can the photograph.

After the liquid has splashed off the right wall and ceiling, it begins to slosh towards the left side of the tank, as shown in Figure 4 (top). The FLUENT simulation of the same time (bottom) once again captures the liquid motion. As in Figure 3, velocity vectors are shown in the liquid, colored by static pressure.

In summary, the flow inside a tank undergoing a periodic swaying motion has been simulated using FLUENT's VOF model. The results are in good agreement with experimental data in terms of period, amplitude, and the overall trends in the time history of static pressure at the walls. Anomalous peaks in predictions of the static pressure were observed. These can be attributed to the impact pressure caused by the liquid striking the wall, which might not have been captured adequately with the laminar flow and shear-free wall conditions used.

Reference:

Hadzic, I., Mallon, F. and Peric, M., Numerical Simulation of Sloshing, Proc. SRI-TUHH Mini Workshop on Numerical Simulation of Two-phase Flows, Ship Research Institute, Tokyo, Japan, 2001.

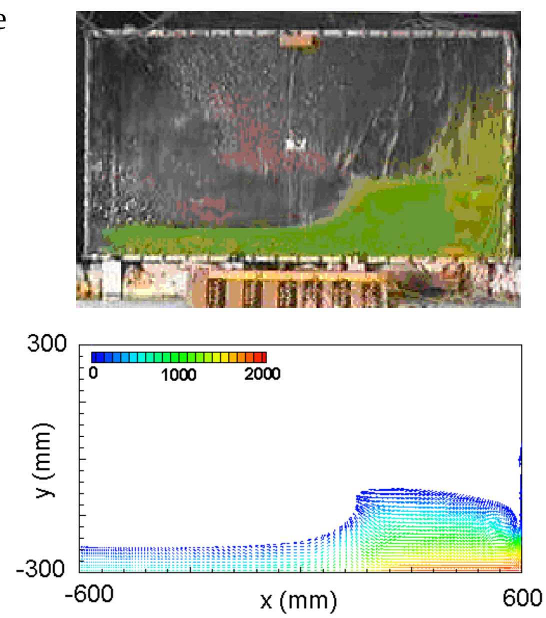

Figure 4: FLUENT results (bottom) at a later time in the oscillation cycle are compared to a photograph at the same time